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ABSTRACT

This paper reports an action study of conceptual change in mechanics using an instructional strategy based on a constructivist view of learning. The aims of the study were to determine: (1) what effect the instructional strategy had on achieving conceptual change; (2) what devices or strategies students used in their attempts to understand physics, and which of these factors were important; and (3) how robust new conceptions were, and to what extent they were used in unfamiliar situations. Seven students in a mechanics section of a first-year physics course were observed during a 12-week period. The instructional strategy consisted of three stages: introduction of POE (Predict, Observe, Explain) experiment, use of qualitative problems related to the concept under consideration, and provision of problems through worked examples by the teacher. The data were collected from audiotaping of classroom sessions, written responses for the POE experiment, problem solving responses, course assessment materials, and interviews. The results indicated that although some success was achieved, obtaining long-lasting conceptual change was a difficult process. The students assessed the course as interesting and relevant, but these features alone were not sufficient to promote change. A lack of awareness of conceptual change was evident among the group. (YP)

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Conceptual Change and Physics Instruction: A Longitudinal Study

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Introduction

Research studies on the learning of science have shown that many students often use concepts other than those formally introduced in the classroom to interpret natural phenomena. The nature of these concepts and their role in the learning and teaching of science has been the subject for many studies in the field of science education (eg. Driver & Erickson, 1983; Hills, 1989; Reif, 1987). Recently, researchers have begun to pay more attention to the role these concepts play in learning science. More specifically, they have investigated ways in which these "alternative conceptions" (as they will be referred to in this paper) can be modified by instruction to achieve a more scientific view (Champagne et al., 1985; Clement, 1987; Hewson, 1981). These conceptual change studies have shown that alternative conceptions are strongly held by students and highly resistant to change or replacement by instruction.

This paper reports an "action research" study of conceptual change in mechanics using an instructional strategy based on a constructivist view of learning (Gunstone, 1988a; Osborne & Freyberg, 1985; Osborne & Wittrock, 1985). The descriptor "action research" is used as the research took place in the context of a normal classroom with the usual curriculum and assessment demands, and the teacher of the class was one of the researchers (the first author). The aims of the study were to determine:

(i) What effect the instructional strategy had on achieving conceptual change in a conventional classroom setting.

(ii) What devices or strategies students use in their attempts to understand physics, and which of these factors are important in achieving conceptual change.

(iii) How robust new conceptions are, and to what extent they are used in unfamiliar or stressful situations (such as formal examinations).

The Context of the Study

The location of the research was a small country college of advanced education (approximately 3000 full time students) in Victoria, Australia. The research focussed on students enrolled in the first-year of a 2 year course specializing in scientific instrumentation. Normal entry into the course requires students to have passed a physics subject at Year 12 level. As with most other tertiary institutions in Victoria, a special entry scheme is available to mature-age applicants without a normal school background. Of the 7 students (all male) who were the subject of this research, 2 were admitted under the special-entry provisions. Thus it can be assumed that 5 of the group have a recent successful background in physics at Year 12 level, and that the remaining 2 students have been assessed as having sufficient background in physics to undertake a first-year tertiary physics program.

The instructional strategy described below was used in the mechanics section of the first-year physics subject (Applied Physics), comprising 4 hours classroom teaching and 3 hours laboratory teaching each week. The strategy was conducted over a period of 12 weeks, although additional data was collected at various times following the completion of the instruction phase of the project.

Teaching Strategy

The broad aims of the teaching strategy were twofold. In the first instance it was designed to enable individual students to become aware of their own ideas, as well as those held by other students in the group. The alternative conceptions that were identified were then used as the basis for change to a scientific view. In essence the teaching strategy was aimed at giving all students an understanding of the basic concepts of mechanics. The second aim of the strategy was to encourage students to use these basic concepts in the solution of "real world" and physics textbook problems.

The strategy can be considered to have 3 main stages:

(a) Introduction of a topic or concept via a POE (Predict, Observe, Explain) experiment or demonstration experiment. The POE strategy has been used in science education research to determine student alternative conceptions (eg. Champagne et al., 1979; Gunstone and White, 1981; Searle, 1986). The focus in this study was to use the POE technique not simply to uncover the range of student ideas, but to use these ideas as a vehicle for discussion aimed at conceptual change. This approach is based on the premise that all students will improve their level of understanding, since:

(i) Those with the "correct" conception become aware that there are other (not necessarily correct) ways of explaining a given phenomenon. By analyzing such explanations and comparing them with their own ideas, a strengthening of their own view will be achieved. This is particularly true if the student can be challenged to defend his/her view in the face of "alternative" explanations.

(ii) Students with alternative views are encouraged to defend their views through either group or teacher-led discussion. With guidance provided by the teacher or other members of the group, this discussion phase will eventually lead to a consensus view of the phenomenon that is in accord with the generally accepted scientific explanation.

The discussion process outlined above requires a classroom environment in which each participant feels free to express a view without fear of ridicule or condemnation by any member of the group. It also requires members of the group to support their view in order to convince others of it's validity and usefulness. That is, each view is accepted for what it is - a genuinely held belief - which is then discussed and compared with other views in a dispassionate, but critical manner. For many science students, this approach is a new experience, as most have not had the opportunity to openly express their ideas in the conventional classroom environment.

In summary, the POE strategy encourages students to express their own views about a

given situation; allows a subsequent discussion of those views, where they can be articulated and challenged; this in turn can lead to a consensus scientific view of the phenomenon.

(b) The second phase of the program is the use of qualitative problems related to the concept under consideration. The qualitative problems are used firstly in general class discussion with further problems used for homework or revision purposes. The class analysis of non-mathematical problems serves to reinforce and apply the scientific view generated via the POE experiments and subsequent discussion. Furthermore, the process can be used to uncover and challenge additional alternative conceptions that may not have become apparent in previous discussion.

The first two phases of the strategy are designed to provide strong basic principles from which the more conventional quantitative physics problems may be tackled with confidence - the third phase of the strategy.

(c) Qualitative problems are introduced via a worked example (or examples) provided by the teacher. Textbook problems of graded difficulty relevant to the concept under consideration are then set for homework and tutorial sessions.

Data Collection

The teaching strategy was implemented during the 4 hours of classroom teaching in Applied Physics each week. The bulk of the data was collected during this period. However one important aspect of the research - individual interviews - was undertaken during the 3 hour laboratory session. The laboratory session was chosen to ensure all students would be available, and to prevent overloading an already crowded timetable. (Students enrolled in the Scientific Instrumentation course have a weekly load of 26 class contact hours, with classes held on two campuses.) Although the interviews would disrupt the laboratory sessions to some extent (each student being absent from the classroom for 20-25 minutes), it was decided the advantage of student availability on a regular basis was more important to the smooth running of the project. There was the disadvantage of the teacher/researcher (first named author) not

being available for teaching in the laboratory. Although the teaching strategy did not include a formal laboratory phase, the laboratory is an area in which individual contact can be achieved with students. Ideas and concepts that arise from the practical work can be discussed and analyzed, leading to a deeper insight into the way in which each student relates physics to the world about him.

The data collected during the study comprised:

(a) Audiotaping of classroom sessions. As the class size was small (the 7 students comprised the complete class), it was possible at the start of each class to rearrange the classroom furniture from the normal linear array of chairs and tables, to an "open square" format. This format enabled each person to have eye contact with other members of the group, a factor that would allow discussion to occur more freely than in the normal classroom arrangement. It also promoted the role of the teacher/researcher as a member of the group, rather than the more usual role as an authority figure disseminating information to those able to receive it.

(b) Written responses to POE experiments.

(c) Problem solving responses of students. At the beginning of the course each member of the group was issued with an exercise book containing duplicate pages. Students were asked to use the books for all problem solving, and the duplicate pages were collected periodically by the teacher/researcher. The original copy was retained by the student for assistance with revision.

(d) Assessment materials. The Applied Physics subject is formally assessed using a 3 hour Examination at the end of each semester (each 40% of the total assessment) and 5 assignments/problem sheets issued throughout the year (20%). Three assignments were completed during the mechanics section of the course. Students had one week to complete an assignment. The written responses to the assignments and semester examination were collected. The details of the assessment tasks were determined by the teacher/researcher.

(e) Individual interviews. Ten interviews were conducted with each student, including one before the commencement of the teaching strategy and two held after the semester examination. The interviews explored student's recollections of previous physics instruction; their strategies used in solving qualitative and quantitative problems; their awareness of conceptual change, and; their perceptions of the usefulness or otherwise of the teaching strategies adopted by the researcher/teacher.

As with most action research projects in education it is not possible to measure or control the way in which data collection effects the instructional strategy being investigated. This was particularly the case with the individual interviews, which were essentially non-structured in nature. In broad terms the same topics or concepts were covered with every student, but the line of questioning was in many cases determined by student responses. As the interviews required the subject to think about and reflect on various phenomena in physics, there would be some effect on student learning - it would disappointing if this were not the case. However, the nature and extent would vary from one individual to another. We believe a more realistic approach to this situation is to regard the interviews as an integral part of the teaching strategy. From this perspective, they can be considered to be similar in function to the POE experiments which serve as both data collection and learning enhancement instruments.

Results and Discussion

As mentioned earlier, the aims of the research were to examine: the effectiveness of the instructional strategy in achieving conceptual change; the devices and strategies used by students to understand physics and their importance for conceptual change; and the strength of any new conceptions. The results reported here are from one student in the group of seven. The student was chosen for the diverse range of views he expressed, his use of analogies as a learning strategy, and because he was one of the more articulate and outgoing individuals in the group. Initially, selected strategies used by the student will be described and discussed. This is followed by an

examination of the robustness of new concepts. Finally, within the context of these two factors, the effectiveness of the instructional strategy in achieving conceptual change will be assessed.

Student devices and strategies.

The following discussion of strategies used by the student is by no means comprehensive. By this we mean that the student under review (as well as other students in the group) may have used other strategies, or have placed differing emphases on the ones discussed here. However the discussions do serve a useful function in providing an insight into some of the attempts of one individual in making sense of physics. The strategies and devices discussed are: prior experiences, analogies, and formal principles.

(a) Prior Experiences. In response to a question in the first interview about how he goes about understanding new ideas, the student replied: (Student - S1, Researcher - R, ... denotes pause in conversation).

> S1: I always seem to understand things a lot better if... if I can see the purpose of something. That's one of the things that really turned me off about Form 6, that (when) we were doing physics in Form 5 we had a teacher who... had a way of explaining things, put them into practical (terms). Like we were doing gravity and forces and that sort of thing and played around in lifts one day with scales... you could see it...
>
> R: Changing?
>
> S1: Yes... you could understand it that's what I think. The next year it was all blackboard work, and the guy who was teaching must have been there for about 15 years and he just had a list of notes, he just wrote it out. Just wasn't of interest at all. I just couldn't get into it.

The experiments in "... lifts one day with scales" was a meaningful event for this student. It took place 5 years previously at Form 5 (Year 11) level, and was regarded by the student as an example of good teaching since: "... you could see it.." and "... understand things a lot better if I can see the purpose of something...". This conformed with his view of learning for understanding. It was also a positive

experience given his comparison with the approach adopted by his Form 6 (Year 12) physics teacher.

The significance of the event and it's importance to learning became apparent in the interview held in week 5 of the 14 week programme. Each student was asked to "think aloud" as they answered questions relating to the forces acting on a child jumping on a trampoline. Initial responses of the student (S1) indicated that he held a "force in the direction of motion" conception. Discussion ensued in which other examples were considered in an attempt to expose contradictions in some of the ideas expressed by the student, as well as promoting a "force in the direction of acceleration" concept. After agreeing with the researcher that when the child is moving upward the resultant force was in fact downward (and more importantly in the direction of the acceleration), the following interchange took place:

S1: Yes. The only way for that to be correct, for the force acting up, would be if (it) was like a rocket or something.
R: Yes. And that would mean that... well, what would that mean as far as acceleration and forces are concerned? If it was accelerating... in other words it is getting faster, what does that tell you about the force applied by the rocket and the weight of the rocket? The sizes of the two?
S1: Say if the rocket was going up?
R: And it is accelerating up.
S1: Well the weight of the rocket, if it was accelerating would be greater.
R: Greater than the force applied by the rocket?
S1: If you're on the rocket it would be relativity... if you're standing in a lift, and standing on scales, and you push "go" up to the next level, you seem to have gained weight. Because you are accelerating up, and because gravity is trying to push you down, causes more weight force.

The student has extended the trampoline problem to consider a rocket accelerating upward. Although agreeing with the concept that net force is in the direction of acceleration for the trampoline example, the concept has not been applied to the rocket. Prior alternate conceptions held by the student appear to dominate the recently accepted scientific conception. This is an example of the fragility of newly "acquired" conceptions. We believe the use of the alternate conception to explain the forces acting on the rocket is the result of a number of influences:

(i) Prior experiences. The use of general principles to solve problems has been shown to be a trait exhibited by expert problem solvers, whereas novices tend to concentrate on surface features in their approach. Thus, although student S1 is in agreement with the "force in direction of acceleration" view the temptation to explain the problem by making an analogy with an upward accelerating example with which he is familiar (the lift), is the chosen strategy - it is a "significant event" in the learning experiences of this student. Irrespective of what the Form 5 teacher intended the class to gain from the lift experience, student S1 has developed an "increased weight causes acceleration" concept. (We have assumed of course, that the conception developed in conjunction with the lift experience. An alternative scenario is that the "seeds" of the conception were apparent before or after the event, with the lift experience acting as a "catalyst".) It appears then, that the subject regards the rocket example as not in the same class of problems as the trampoline problem (ie. those that can be explained by using a force in direction of acceleration view). It would be interesting to contemplate the approach taken to the rocket problem if the lift experience had not occurred in Form 5.

(ii) Egocentricity. The rocket problem is seen from a personal standpoint. That is, the student relates the problem to himself, and to events that he has experienced in lifts. For example (emphasis added): "... if you're standing in a lift, and standing on scales, and you push "go" up to the next level, you seem to have gained weight. Because you are accelerating up, and because gravity is trying to push you down, causes more weight force." This personal viewpoint created difficulties for the student in the rocket problem since the perceived forces acting on him were transferred to the rocket example. Again, this expression of the problem in personal terms is a characteristic of novice problem solvers described by Chi et al. (1981).

(b) Analogies. In the previous section we have described the way in which student S1 has used an analogy in attempting to explain the rocket example. This appears to be one of two ways in which the subject uses analogies to gain an understanding of physics: the understanding of an analogy is applied to the current problem, and; an

understanding of the current problem is applied to an analogy. For the purpose of discussion in this paper we have designated the two processes as Type SA and Type SB respectively (Fig 1). Hence the lift/rocket problem is an example of a Type SA process.

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Figure 1 about here

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The Type SA and SB processes outlined above are initiated by the student as an aid to understanding. Teacher-introduced analogies are also a part of the learning process, with Clement (1987) using them in a strategy designed to overcome misconceptions in physics. Again there appear to be 2 broad categories of classification. The first (Type TA) are those in which an understanding of the current problem is to be extended or tested by application to an analogy. The second type (Type TB) describes a process in which a student does not have a full understanding of the current problem, and an analogous situation is introduced (that the student may understand) in an attempt to achieve transfer of understanding to the original problem (Fig 2).

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Figure 2 about here

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As far as learning outcomes are concerned, we suggest that teacher-initiated analogies may be less successful than those initiated by students. This is because Type TA and TB processes depend on both the student recognizing the validity of the analogy, as well as achieving successful learning transfer. In the student-initiated cases the analogy is recognized (otherwise it would not have been introduced), and only learning transfer is necessary. A note of caution is required here, since we have assumed in our broad classification that the analogies used are appropriate, for the person advancing the analogy, and that the understanding (of either the current problem or the analogy) is compatible with the scientific view. In the real-world classroom such ideal situations

rarely exist, and so learning "distortions" are bound to occur. For example, in the rocket/lift analogy, a transfer of alternate conceptions occurred - presumably reinforcing the conception - because a comparison was made with a well understood analogy (as far as the student was concerned). Examples of the 4 analogy processes used in the learning strategies of student S1 are outlined below:

(i) Type SA process. Another example (in addition to the lift/rocket example) of a Type SA process is illustrated by consideration of a class discussion held during week 4 of the programme. The class were discussing the weight of a sealed glass jar of flies. The question under discussion was:

> Is the weight of the jar lighter, heavier or the same, when the flies are flying in the jar?

The transcript of the discussion included the following exchange:

> (In the discussion prior to this exchange, two students expressed ideas that indicated the weight of the jar would not alter.)
>
> S1: I think there would be a difference between ... I think when flying there would be no force on the jar caused by the flies. When they land, there would be.
> R: You're saying it would be less when they fly.
> S1: That's probably wrong, but that's what I'd say.
> R: Why do you think it is less though, because...
> S1: Because they're not on the actual glass. The only thing they are on ... they are supported by the air.
>
> (Further general class discussion followed - not involving S1 or consideration of his proposition.)
>
> S1: I've been trying to think about this [situation]. What about those things you see in carnivals and that, kids are jumping around on those air bag things. While they are in mid-flight they aren't exerting any force whatsoever on the bag.
> R: I'm not quite with you ... oh, those air castle things?
> S1: Yes. So I can't understand why those are exerting a force, while they are flying around in the actual jar itself.
> S2: Those kids aren't in mid-flight, because they have propelled themselves. Once they are in mid-flight there is no force pushing down, there is no force pushing down to hold them up in the air. Whereas these flies are staying up in the air because they are [pushing the air down?]

The student (S1) has used the air castle analogy as an aid to learning. He believes his explanation of the analogy should be applicable to the current problem. It is interesting

to note that this applicability of ideas across different contexts appears to be strong only in cases in which the learner has a large stake in the process. That is, the learner has been actively involved in the development of the ideas and is determining if they are "fruitful", to use the conceptual change term introduced by Posner et al (1982). In contrast, lack of applicability across contexts is a common feature when the use of formal physics principles is considered. (See later in this paper.)

In the context of this research study, there are two further aspects worthy of consideration from the above discussion. The first is that the student (S1) is actively engaged in the process of finding an explanation that is suitable to him - in constructing a view that is consistent with his existing frameworks. Two other students had provided answers (substantially correct) to the jar of flies problem, before S1 offered his view. He hasn't been convinced by other student ideas, and feels confident enough to test his ideas on the group. He obtained no support for (or criticism of) his ideas initially, but returned to the discussion using the air castle analogy to substantiate his argument. The second point is that another student (S2), was able to put forward an argument as to what he regards as the similarities and differences between the analogy and the original problem. Both aspects relate to an important perspective of the teaching strategy used in this research. The creation of a classroom environment in which students feel free to express and test ideas on the group is of paramount importance to the success of the strategy.

(ii) Type SB process. During week 3, vector concepts and vector addition were introduced. After working through a conventional example of a boat travelling across a moving river, the researcher initiated discussion on the concept of relative velocity. As far as an observer on the river bank is concerned, the boat would travel in a straight line at some angle to the bank. Student S1 was not convinced of this suggestion, as his analogy with a real situation (a windsurfer) indicates:

S1: Wouldn't that go in a curved line?
R: Why do you think it would be a curved line?

S1: Well, when you go sailing, if you're on a sailboard or something, and you're going square to the wind, if you look behind you...
R: Hang on, what does square to the wind mean?
S1: You are ninety degrees to the wind, and so instead of having the current of water acting on you, you'll have the strength of the wind in the same direction.
R: So the wind is going that way.
S1: Yes, and you're sailing across it at right angles. If you look behind you, you can see (the curve in the wake).

(Further discussion is then concerned with analyzing the complexity of the windsurfer example.)

The point at issue here is that the student has (apparently) understood the worked example, but it is not in accord with his real-world analogy. We contend that full understanding would not occur unless (or until) the student was satisfied that the vector addition concepts resolved his windsurfer problem.

(iii) Type TA process. One way of testing depth of understanding is whether or not concepts can be successfully applied across different contexts. During the individual interviews in week 6, students were asked to think aloud while considering their solution to the following problem (Clement,1982). The diagram used in the problem is illustrated in Figure 3.

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Figure 3 about here

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The accompanying figure shows a rocket coasting in space in the direction of the dotted line. Between A and B, no outside forces act on the rocket. When it reaches point B, the rocket fires its engines as shown, and at a constant rate until it reaches a point C in space.
What path will the rocket follow between B and C? Draw in the path on the diagram.

On being satisfied the student had a grasp of the concepts involved, the researcher introduced an analogous situation:

R: ... Can you see any similarities between that and some of the other work we've done up until now?
(Pause)
For example, can you see any similarity between that problem and projectile motion, for example?
S1: Yes, but in this case there is no gravity. There's nothing opposing it, because it is in space.

R: Right, so in what way is it similar, then. You're saying it is similar, so what's similar about it?

S1: Well, on earth, frictional forces are applied where this is basic, straight down to earth, nothing.

R: No friction. yes.

S1: No friction, or deacceleration due to gravity. Like say if the rocket was... say if they were speedboats or something like that, to go forward it would have a friction due to the water trying to slow it up.

R: What about the shape of the path there. Going back to projectile motion, for example, you said a couple of weeks ago on one of the problems, with the cannonball one, that it was a parabola. Would that be a parabola, or something different?

S1: It would be the inverse of a parabola ... hang on ... if you plotted the graph of projection of a projectile falling, or going along at a constant velocity or something ... it would fall in that manner. And the acceleration of that towards the ground would be "g". And in (this) case because B is doing the acceleration and there is nothing opposing it, that you'd have to assume that graph would have to be turned around the other way, or the path would have to be turned around the other way.

R: Right, so it's still a parabola but just flipped up the other way.

S1: Yes.

The analogy was intended to focus on the similarity between the shapes of the path taken when the rocket was under power, and projectile motion. Both are examples of constant velocity in one direction combined with acceleration in a perpendicular direction. The subject failed to see the similarities between the motions, and instead focussed on the surface differences, such as friction. After the researcher suggested a consideration of path shape, the student began to realize that the motions of the two objects were similar. We speculate that, if the rocket problem had been drawn so the path was oriented to be the same as projectile motion, the student may have recognized the analogy more easily.

(iv) Type TB process. The concepts of conservation of energy and conservation of momentum were introduced during week 9. At the individual interviews held at the end of that week students were asked to consider the following problem (Champagne et al., 1982).

A boy is standing on a floating raft on a lake. It can move on the surface of the lake with negligible friction. Starting from rest, the boy begins to walk with constant speed towards the shore. Describe the motion of the raft. How does the speed and direction of the raft compare with the speed and direction of the boy?

Although his initial response to the problem was correct, student S1 was not confident of his reply, as indicated by the following dialogue:

S1: The boy's on the raft (S1 draws a diagram) ... walking that way.
R: So the shore is over to the right?
S1: Yes,...the raft will go that way. That's assuming that he's got friction between his feet and the raft.
R: Yes, fair enough, but none between the raft and the water.....
S1: The raft and the water.
(A long pause follows)
R: Well you were saying that the boy's going toward the bank and the raft will go backwards... you're not happy with that?
S1: No, not really. It will stay there and he'll just walk off the end of it.
R: The raft will stay there?
S1: Yes. It won't move.
R: Why do you think that?
S1: What we are really talking about, we are talking about the system, the boy and the raft, as much as the raft and the water. Now he is walking, he is applying a force there, but... there's nothing else, that's it. So he's applying a force to walk against the friction, when he takes his step, and he's actually just walking on the raft, he's not pushing ... if he was attached to something, if he say grabbed hold of say a branch and he started walking, then it would move backwards, because then it's...
R: The raft would move backwards?
S1: Yes the raft would move backwards. Say if he grabbed hold of a branch and walked,...
R: So he would stay still relative to the branch, and the raft would go backwards?
S1: Yes, the raft would go backwards.
R: So in this case, what is different about this case? Or are you saying it is the same?
S1: Yes, I'm saying in this case that he's actually on the raft, and the raft relative to him, looks like he is moving forward, but the bank looking at the boy, the boy would walk off the end.
R: The raft would ...
S1: The raft is still in the same position, it is not moving anywhere.
R: So relative to the bank, the raft appears to stay where it is, and the boy comes off the front?

S1: And he walks off the front. Now if he grabbed hold of something like a branch or something, and started walking, because...
(A long pause follows.)

At this point the researcher, knowing that S1 has a windsurfer (see Type SB example) introduced the windsurfer analogy as a means of resolving the uncertainty in the discussion.

R: You've got a windsurfer haven't you?
S1: Yes
R: Have you ...
S1: I've walked down it no worries and it hasn't moved ... or it shouldn't. If you dive off the end it's a different matter of thing. If you dive off...
R: What do you think is the basic difference between diving off and walking quickly,... diving really is just walking except there is no raft in front of you isn't there?
S1: I don't know.
R: I mean it is not a perfect example of this anyway because there is friction between the surfboard and the water. But your experience is that it doesn't move at all, when you move to the front?
(A long pause follows.)
S1: It should move back. Trying to get it all (together) ...look at the whole thing. He's walking this way, force he applies, must be an equal and opposite force. So therefore ..
R: So you are saying there is a force by him on the raft
S1: Yes.
R: What about the forces on him?
S1: There's air.
R: Anything else? You mentioned equal and opposite forces a minute ago ...
S1: And the weight force.

(There followed further discussion regarding the forces acting on the boy and the raft.)

The relevant issue under consideration here is that although an example familiar to the student was chosen as the analogy (the windsurfer), the strategy did not achieve an understanding of the original raft problem. Possible reasons for the failure of the analogy are: it was "imposed" on the student rather than initiated by him; the student was not totally sure of his experience on the windsurfer - " I've walked down it no worries and it hasn't moved ... or it shouldn't. If you dive off the end it's a different

matter .." - and so was not a strong, and perhaps even a confusing experience on which to base the analogy.

(c) Formal principles. The formal principles of physics - such as Newton's Laws and the Conservation Laws - are generally not invoked by student S1 in his approach to solving qualitative problems. He considers the surface features of problems before (if at all) any general principle is used to produce a solution. This trait is not surprising in view of earlier evidence for S1 as a novice problem solver. For example, in discussing the boy on the raft problem approximately 10 minutes were spent discussing the forces acting on the system before the word "momentum" was mentioned. The use of (conservation of) momentum appeared to have been triggered when the student was asked to compare the speeds of the raft and boy:

S1: See, the point they were at, the instant before he started walking would be there, and afterwards the boy would be there and the raft would be there. At supposedly equal distances ...
R: Well, that's the second part of the question actually, how do those 2 velocities compare? One goes one way and one the other ... and you've got 3 choices: either the velocity of the boy is larger, equal to or less than that of the raft.
S1: If it is frictionless, it will be the same.
R: Right , why will it be the same?
S1: Oh, hang on...
R: So you're saying ... sorry ... so do you think ...
S1: Momentum will be the same, but the velocities are different because the masses are different.
R: So if it is a very large raft, large mass compared to the boy?
S1: He would move it backwards with hardly anything.
R: And if it was small compared with the boy?
S1: It would shoot right out. Like a sailboard, if you dive off the edge it will go 10 feet in the opposite direction.
R: Yes, because it is a lot lighter than you are.
S1: That's why ocean cruisers don't go backwards when you walk up and down on them!

It is interesting to note that once invoked, the principle enables the student to explain and extrapolate to the movement of sailboards and ocean liners. That is, he had sensed the power and fruitfulness that comes with an understanding of the concept.

A common characteristic found among many novice physics students is their lack of application of formal principles and concepts in problem solving (Chi et al., 1981). This

factor has been highlighted in the above example. A further characteristic that inhibits learning is the misuse or misunderstanding of formal principles - alternate conceptions. That is, when principles are applied they are often misinterpreted, or not used in an appropriate context. This feature is described through an alternate conception of Newton's Third Law held by student S1. The view was expressed by S1 during a class discussion in week 4 of the programme. The discussion, designed to determine student ideas about the forces acting on a unpowered sledge moving on a horizontal bank of snow (Figure 4), produced the following exchange:

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Figure 4 about here

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R: What is the cause of F1? [The force F1 in the direction of motion was included on a force diagram by a number of students, including S1]
S3: F1 is due to the velocity.
S1: Reaction against friction. Friction is going this way, there will have to be a force going the other way to counteract the force of friction.

Although not stated, Newton's Third Law - or more correctly the student's conception of the Law - was applied to justify the existence of the force F1, and the motion of the sledge. The "impetus" view of motion expressed by S1 is an alternate conception found among a wide range of students (McCloskey, 1983). In this case however the view was supported by invoking a scientific "law" (albeit an alternative conception of the law), and the effect may have been to reinforce the view more strongly in the mind of the student. Newton's Third Law had not been discussed in class prior to week 4. However, the "Minstrell sequence" (Minstrell, 1982) was used in the previous lesson to introduce the notion of normal reaction, and the student may have utilized some of the concepts from that discussion in his explanation.

Further class discussion then ensued in order to ensure that students were aware of his alternate conception, and to promote a change of view to the accepted scientific

one. The effectiveness of the strategy is discussed in the following section in which the robustness of newly acquired concepts is considered.

Robustness of new concepts.

As this paper is concerned with conceptual change it is appropriate to consider the robustness of concepts that were altered during the programme. Although an obviously related topic, we will not consider (in this section) examples where conceptual change did not occur. The focus of our discussion will be on the student's ideas about force and motion (linear and rotational), and the influence of his view of Newton's Third Law on those ideas.

Linear Motion. As described above, student S1 expressed an alternate view of the Third Law during week 4 of the programme. The following week, (week 5), students were asked to predict the position, as well as the forces acting on a pendulum bob at the rear of an accelerating cart. The exercise was part of a POE experiment designed to determine student ideas about forces and their role in constant velocity and accelerated motion. The diagram produced by student S1 for the POE is reproduced in Figure 5.

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Figure 5 about here

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The explanation given for his choice of forces was:

> When the cart is started the ball will move away from its equilibrium position to somewhere in the direction opposite to the carts acceleration. This is caused by the force F1 (due to the air) and the reaction force of the cart compared [sic] to the ball.

The student appears to be using the notion of a counteracting or opposing force to justify his choice of the force 'a' in the direction of motion. In addition to this response there appears to be a lack of differentiation between acceleration and force. This lack of differentiation between concepts as a characteristic of beginning physics students is outlined by Champagne et al., 1985. A force in the direction of the

acceleration is given the label 'a'. This may have been due to the student believing that a component force was needed in the direction of the motion. However this appears unlikely, since his diagram for the net force acting on the bob indicates a "balance of forces" notion rather than a net force notion. In an effort to resolve and clarify the student's ideas about this example, they were discussed further at the individual interview at the conclusion of week 5.

R: Alright, so we've got friction force that way, and the last force there? [The researcher is referring to the force labelled 'a' on the diagram]

S1: I was assuming that, I was thinking of reaction between air and the ball ... which is not ... just a reaction force. I thought the frictional force was going in such a direction there has to be something opposing it.

R: Oh, yes, the sort of thing you were talking of the other day.

S1: Yes, so it was the friction of air on the ball, so it hasn't got anything to do with the ball at all. On what we are looking at anyway.

R: So what is the reaction force that you ...

S1: That's the reaction force with the ball and the air.

R: Right, so it's the force acting on what?

S1: On the air itself.

R: On air, OK. Yes, I think as Steven [another student in the group] was saying, I think that it comes from your idea that: "To every action there is an equal and opposite reaction" ... Newton's Third Law ... which is true, but you've got to be careful about what the forces act on. This is a friction force acting on the ball, which there is, there is an equal and opposite force to that, but it acts on the air.

Student S1 appears to have become aware of his previous use of the Third Law - "I thought the frictional force was going in such a direction there has to be something opposing it." - and accepts that the force 'a' is a force on the air and not the ball.

Circular motion. However, the balance of forces conception (Searle, 1986) was used one week later (week 6) in explanation of the motion the moon around the earth. Circular motion had been introduced in classroom discussions during week 6. The question posed during an individual interview at the end of that week was: "The moon revolves around the earth in a circular orbit. What are the forces acting on the moon

as it moves around the earth?" The transcript of the interview included the following dialogue:

S1: The reason why it doesn't go [in towards the earth] is because they are both equal.
R: How do you mean they are both equal?
S1: Well, if they weren't either the moon would move away from the earth, or hit the earth.
R: Yes, but what are both equal? You say they are both equal.
S1: They would have to oppose each other I think.
R: Oh, you mean another force out in that direction, away from the earth, sorry, away from the moon. Why do you want to ... so a balancing force ...
S1: There would have to be, because or else, if that span around it would hit the earth.
R: It doesn't obviously, but why ...
S1: Oh, hang on, ... no taking away centripetal force, taking away the force trying to push it out, which is, ...
R: Centrifugal?
S1: Yes. That's right, centripetal is not pushing it in is it? Centrifugal force out that way, and the force trying to attract each other [the moon and earth] that way.
R: So they are equal, but opposite?
S1: Yes, if it was unbalanced it would head off that way, or hit the earth.
R: Or if the other one was bigger, it would go away from the earth?
S1: If the other one was bigger it would just move out here.
R: To a different orbit?
S1: Yes, depending on ... it would be proportional to the actual mass difference, how far it went out.
R: What causes the centrifugal force then, the outward one?
S1: Due to the moon rotating around the earth, and because there is nothing to oppose it. If you just had that without the ... neglecting the force of attraction, if you didn't have it, there would be nothing to oppose it. Like going around in a circle, you've got the friction to oppose [the] force to throw you out. Say that's the friction of the tyres which actually holds you on ... because you can feel the sensation of being pulled into the centre. In this case there is nothing to counteract it, in that ... without thinking about the masses are going to attract each other. So there is nothing to oppose it, so centrifugal force would be trying to push you out all the time. And because the two masses attract, that's why they are in orbit.

When confronted with a different context (circular motion) the concept of a counteracting force is again utilized. The use of a "balance of forces" notion is not

uncommon (Gardner, 1984; Searle,1986). Here student S1 justifies his choice of a balancing force by:

(i) using his concept of the Third Law for an "opposing force" on the force diagram, supported by personal experience with motor cars - ".... you can feel the sensation of being pulled into the centre."

(ii) the necessity for a balance of forces to achieve a constant distance from the earth - ".... if it was unbalanced it would head off that way, or hit the earth."

Circular motion was also the focus of a qualitative question included on a "take home" assignment issued in week 7 of the programme. The question was:

> A bucket of water is rotated in a vertical circle at a speed such that the water does not come out of the bucket at any location in the circle. Why doesn't the water fall out of the bucket at the top of the circle?

The explanation given by student S1 was:

> When the bucket rotates around a point an centripetal acceleration is caused this is directed at the centre. This is at the bucket of water. The water has a reaction force R to the bottom of the bucket is centre seeking of centripetal force. So therefore if you were the water it would feel like the bottom of the bucket was forcing you towards the center. Back to the water in bucket. The reason the water doesn't fall out is the centripetal force is greater than that of the weight force.

Although the explanation is incorrect, the student appeared to recognize that there was a force acting on the water towards the centre of motion. There was no reference to an outward force in the explanation, although the notion of forces in opposite directions is inherent in his final statement. (Despite a diagram being drawn by the student forces were not included on it.) It is instructive then, to compare his response to the same question on a supplementary test administered some 11 months later. (Student S1 failed the subject Applied Physics, but gained sufficient marks to qualify for a supplementary assessment at the end of the summer vacation.) His response was:

> When a bucket is flung around at a speed the water will not fall from the bucket because the reaction force opposing the centripetal force ie. between bucket and the water is greater than the force due to gravity.

The balancing forces view is again evident as well as a counteracting force - " .. the reaction force opposing the centripetal force .."

The examples above indicate the fragility of new ideas. Conceptual change when it does occur, is very much context dependent. To become a stable part of a students' conceptual framework, new or changed concepts appear to require frequent use over a wide range of contexts.

Effectiveness of the teaching strategy.

The broad aims of the strategy were to stimulate students to consider their views about various phenomena and (where necessary) promote conceptual change via discussion and use of qualitative problem solving. Student S1 was a willing participant in this process, being a regular contributor to class discussions. However, the achievement of conceptual change in S1 can at best, be described as transient. The data indicates that alternate views are supported and reinforced by both personal experience and alternate conceptions of formal scientific principles. This particular student made use of analogies to assist his understanding, and the use of 'real world' qualitative examples by the researcher/teacher would appear at first sight to capitalize on this method of learning. However, this appears not to have provided the necessary basis for permanent change, even though the student recognized their relevance. In an assessment of the course student S1 stated (in part):

> This our first half of the year has be[en] good in applied physics unlike any other subject it has be[en] made interesting which then encourages us to learn. With the combination of physics pracs Applied physics has drummed (right from basics, very clearly) the topics we have covered. I also like the ideas of assignment sheets these give you a chance to see yourself how you are progressing. These assignment sheets are good because they are interesting and poses real problems. [Emphasis made by student.]

The partial success of the strategy may be due to the student realizing the importance of the problems in making the course interesting and relevant, but not recognizing the use of the problems as an aid to conceptual change.

Conclusions

The research reported in this paper indicates that although some modest success was achieved, obtaining long-lasting conceptual change is a difficult process. The student under consideration assessed the course as interesting and relevant, but these features alone are not sufficient to promote change. Evidence from recent studies demonstrate that an awareness of the thinking process (Baird & Mitchell, 1986) and an awareness of conceptual change (Gunstone, 1988b) may be important elements of any successful teaching strategy.

The present study did not use a metacognitive approach, but a lack of awareness of conceptual change was evident among the group. Student S1, in his final individual interview (3 months after the conclusion of the teaching strategy) made the following comments:

R: With circular motion, seeing we are talking about that, do you think you have changed any of your views about circular motion from when you started?
S1: Oh yes, definitely.
R: That's good, what have you changed?
S1: Well I just thought about it. Like before, I looked at things and I was very confused about when things were rotating. Like on a string and things like that, and I know ... what's actually happening now. I used to be always confused.

Although there is an hint that S1 is aware of his thinking ("Well I just thought about it".), his comment that - "I used to be always confused" - was typical of most members of the class. Responses to questions regarding their awareness of conceptual change could be paraphrased as: "I understand better than I did before, but I'm not sure how it happened." Teaching strategies that promote conceptual change and also ensure students' know how they have changed their views, may produce more predictable and long-lasting change.

References

Baird, J.R., & Mitchell, I.J. (1986). Improving the quality of teaching and learning: An Australian case study - The PEEL project. Melbourne: Monash University Printery.

Champagne, A.B., Gunstone, R.F., & Klopfer, L.E. (1985). Effecting changes in cognitive structures among physics students. In West, L.H.T., and Pines, A.L. (Eds.), Cognitive Structure and Conceptual Change. New York: Academic Press.

Champagne, A.B., Klopfer, L.E., & Anderson, J. H. (1979). Factors influencing the learning of classical mechanics. Report No.23. Learning Research and Development Center, University of Pittsburgh.

Champagne, A.B., Klopfer, L.E., & Gunstone, R.F. (1982). Cognitive research and the design of science instruction. Educational Psychologist, 17(1), 31-53.

Chi, M.T.H., Feltovich, P.J., & Glaser, R. (1981). Categorization and representation of physics problems by experts and novices. Cognitive Science, 5, 121-152.

Clement, J. (1982). Students preconceptions in introductory mechanics. American Journal of Physics, 50(1), 66-71.

Clement, J. (1987). Overcoming students' misconceptions in physics: The role of anchoring intuitions and analogical validity. In J.D. Novak (Ed) Proceedings of the second international seminar on misconceptions and educational strategies in science and mathematics. Ithaca, NY, Cornell University, 1987.

Driver, R.P., & Erickson. G. (1983). Theories-in-action. Some theoretical and empirical issues in the study of students conceptual frameworks in science. Studies in Science Education, 10, 37-60.

Gardner, P.L. (1984). Circular motion: Some post-instructional alternative frameworks. (ASERA Conference, May 1984.)

Gunstone, R.F. (1988a). Learners in science education. In P.J. Fensham, (Ed) Developments and dilemmas in science education. London: Falmer.

Gunstone, R.F. (1988b). Some long-term effects of uninformed conceptual change. Paper presented at the meeting of the American Educational Research Association, New Orleans.

Gunstone, R.F. & White, R.T. (1981). Understanding gravity. Science Education, 65(3), 291-299.

Hewson, P.W. (1981). A conceptual change approach to learning science. European Journal of Science Education, 3(4), 383-396.

Hills, G.L.C. (1989). Students' "untutored beliefs" about natural phenomena: Primitive science or commonsense? Science Education, 73(2), 155-186.

McCloskey, M. (1983). Naive theories of motion. In Genter, D., and Stevens, A.L. (Eds.), Mental Models. Hillsdale, New Jersey: Lawrence Erlbaum Associates.

Minstrell, J. (1982). Explaining the "at rest" condition of an object. The Physics Teacher, 20(1), 10-14.

Osborne, R.J., & Freyberg, P. (Eds.). (1985). Learning in science: The implications of children's science. Auckland: Heinemann.

Osborne, R.J., & Wittrock, M. (1985). The generative learning model and its implication for science education. Studies in Science Education, 12, 59-87.

Posner, G.J., Strike, K.A., Hewson, P.W. & Gertzog, W.A. (1982). Accomodation of a scientific conception: Toward a theory of conceptual change. Science Education, 66(2), 211-227.

Reif, R. (1987). Instructional design, cognition, and technology: Applications to the teaching of scientific concepts. Journal of Research in Science Teaching, 24(4), 309-324.

Searle, P. (1986). A study of the circular motion concepts held by college level engineering students. Unpublished M.App.Sc. thesis, Curtin University of Technology.

APPENDIX

TYPE SA: Understanding of ANALOGY → Applied to CURRENT PROBLEM

TYPE SB: Understanding of CURRENT PROBLEM → Applied to ANALOGY

Student-initiated analogies

Figure 1

TYPE TA: CURRENT PROBLEM (understood) → Applied to ANALOGY

TYPE TB: ANALOGY → Applied to CURRENT PROBLEM (not understood)

Teacher-initiated Analogies

Figure 2

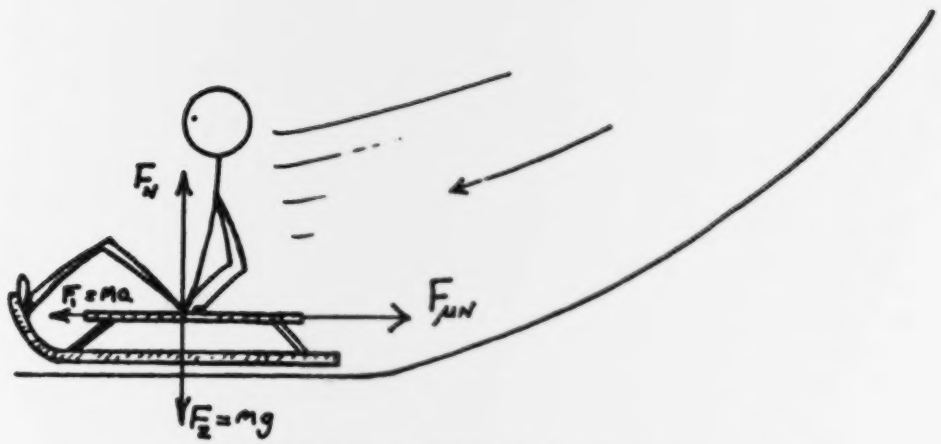
The accompanying figure shows a rocket coasting in space in the direction of the dotted line. Between A and B, no outside forces act on the rocket. When it reaches point B, the rocket fires its engines as shown, and at a constant rate until it reaches a point C in space.

What path will the rocket follow between B and C? Draw in the path on the diagram.

Diagram used in the rocket problem

Figure 3

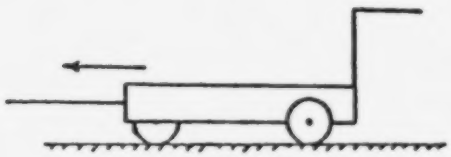
A sledge slides down a hill onto a flat plain. What are the forces acting on the sledge?



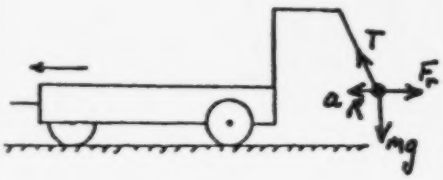
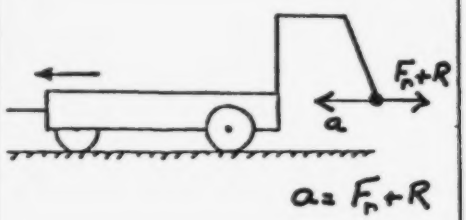
Student force diagram (sledge problem)

Figure 4

The diagram below represents a cart moving across the floor with a constant acceleration. i.e. the velocity changes by the same amount each second. (Again the position of the mass is not shown).



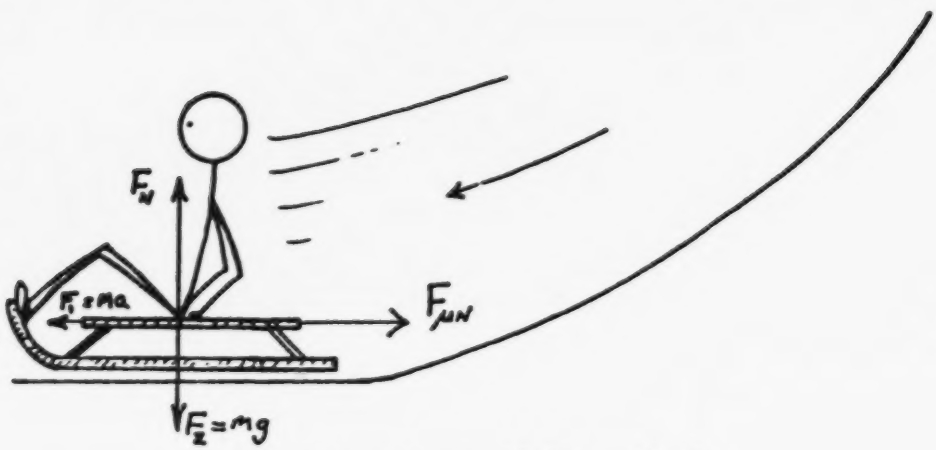
Draw the position of the mass and string on the diagram provided (Diagram A). On the same diagram show all the forces acting on the mass. On diagram B indicate the net force acting on the mass. Again briefly explain your choice of position, forces acting, and net force.

A. *Position and forces acting*	B. *Net force*
	
C. *Explanation*	
D. *Comparison of Observation and Prediction*	

POE experiment (accelerated cart)

Figure 5

A sledge slides down a hill onto a flat plain. What are the forces acting on the sledge?



Student force diagram (sledge problem)

Figure 4

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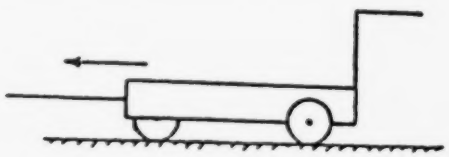
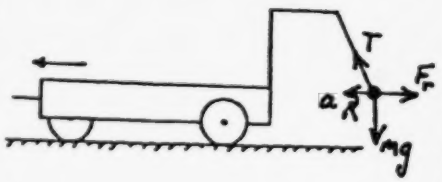
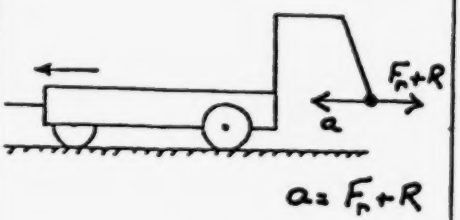


Draw the position of the mass and string on the diagram provided (Diagram A). On the same diagram show all the forces acting on the mass. On diagram B indicate the net force acting on the mass. Again briefly explain your choice of position, forces acting, and net force.

A. Position and forces acting	B. Net force
	

C. Explanation

D. Comparison of Observation and Prediction

POE experiment (accelerated cart)

Figure 5